

Mulch tillage – principle of preservation of chernozem of the northern steppe of Ukraine

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Abstract: Reclamation and intensive utilization of chernozems of the steppe zone of Ukraine over a long period led to loss of a significant amount of organic matter, agrophysical degradation, and dramatic decrease of soil fertility. Organic products of plant origin – byproducts of field crops (straw, frondiferous residues of arable crops) – play an important role in the renewal of fertility, protection of soils from erosion and accumulation of efficient moisture in the soil. The article presents the results of studying of the agro-economic efficiency of board, differentiated and shallow (mulching) tillage systems when growing field crops under the conditions of the northern Steppe of Ukraine. There is substantiated the expediency of use of a shallow (mulching) tillage system, which, in terms of crop rotation efficiency against a fertilized background, is highly competitive with board and differentiated systems, as well as has a positive effect on the structural state of the arable layer (the content of agronomically valuable aggregates is 76 %), provides additional (71-85 m³ ha⁻¹) accumulation of efficient moisture in the autumn-winter period. The most of conditional stubble on the surface remains, of course, in the early fallow (without tillage in autumn) – 630 pcs m⁻². A significant amount of it was also after disk processing – 333 pcs m⁻². Early fallow is a reliable method to wind erosion (deflation) combat in the spring. Even strong winds with a speed of more than 15 m s⁻¹ in early fallow are not able to blow out more than 5-12 g m⁻² of soil in 5 minutes of exposure, while in case of board tillage these figures increase by 11-26 times and amount to 134 g m⁻².

Key words: mulch tillage; agrophysical properties; fertility; crop residues; productivity; humusa

Obdelava tal z mulčenjem kot osnova za ohranjanje črnozema v severnih stepah Ukrajine

Izvleček: Melioracije oz. spremembe naravne stepe v njihove in intenzivna raba črnozemov sta v stepah Ukrajine preko daljših obdobjih pripeljala do znatne izgube organskih snovi v tleh in sprememb v njihovi zgradbi, kar je povzročilo dramatično zmanjšanje rodovitnosti tal. Organske snovi rastlinskega izvora kot so stranski produkti pridelave poljščin (slama, ostali ostanki poljščin) igrajo pomembno vlogo pri obnavljanju rodovitnosti, ščitijo tla pred erozijo in zagotavljajo zadostno zadrževanje vlage v tleh. Prispevek predstavlja rezultate raziskave agroekonomskega učinka različnih sistemov obdelave tal (oranja in mulčenja) pri pridelavi poljščin v razmerah severnih step v Ukrajini. Uporaba sistemov plitve obdelave tal (mulčenje) se izkaže kot primernejša glede na učinkovitost kolobarja in porabe gnojil. Je bistveno boljše v primerjavi z različnimi sistemi oranja. Ima tudi pozitiven vpliv na zgradbo orne plasti tal (vsebnost agronomsko zaželenih talnih agregatov je 76 %), dodatno prispeva k zadostni vlažnosti tal v jesensko zimskem obdobju (71-85 m³ ha⁻¹). Največ primernih rastlinskih ostankov ostaja na površju v začetku praha (brez obdelave v jeseni; 630 delcev m⁻²). Znatna količina teh organskih ostankov ostane na površju tudi pri obdelavi z diskasto brano, – 333 delcev m⁻². Zgodnja praha je primerna metoda za preprečevanje vetrne erozije spomladi. Celotno močni vetrovi, s hitrostjo več kot 15 m s⁻¹, pri zgodnji prahi ne morejo odpihniti več kot 5-12 g m⁻² tal, pri izpostavitvi za 5 minut, medtem ko se pri obdelavi tal z oranjem ta količina poveča 11-26 krat in znaša 134 g m⁻².

Ključne besede: obdelava tal z mulčenjem; agrofizikalne lastnosti; rodovitnost; ostanki poljščin; produktivnost; humus

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1 INTRODUCTION

The strategic goal of Ukraine's agricultural production is an increase of crop yields, significant increase of each hectare productivity to provide sufficient food both for the population and for export abroad, as well as creation of a stable fodder base for livestock. Difficult conditions for the industry economic development require transition to energy and resource-saving agriculture. Herewith, an important task is to preserve and expand the regeneration of potential and effective soil fertility, to maintain environmental safety of agroecosystem. Reformation of the agricultural sector of Ukraine requires improvement of the agricultural system as a whole, therefore, development aimed at forming promising models of agriculture that would simultaneously increase productivity, save energy and resources and preserve soil has strategic perspective (Saiko and Boiko, 2002; Tarariko et al., 2013; Tkalic, 2011).

Therefore, reclamation and intensive utilization of chernozems of the steppe zone of Ukraine over a long period led to loss of a significant amount of organic matter, agrophysical degradation, and dramatic decrease of soil fertility. Over the past 40 years, chernozems have lost 0.5-0.7 % of organic matter. Moldboard tillage is one of the most cost and energy-intensive processes in agriculture, and its implementation in Ukraine consumes about 500 thousand tons of fuel per year. Organic products of plant origin – byproducts of field crops (straw, frondiferous residues of arable crops) – play an important role in the renewal of fertility, protection of soils from erosion and accumulation of efficient moisture in the soil (Adamchuk et al. 2016; Shevchenko et al., 2015; Tebrugge, 2001; Tamames, 2002; Vita, 2007; Cannel, 1985). Crop residues are energy material for arable soil formation and shall be rolled into soil. This makes it possible to close the small biological cycle of substances, opened by the systematic subtraction of most of the biological products of plants. Introduction of crop residues increases humus content, improves soil structure, reduces erosion trend, stimulates nitrogen fixation process. Plant remains are a source of nutrition for soil microorganisms, without which the availability of certain nutrients would be limited. The effectiveness of fertilization with crop residues depends primarily on their harvester grinding, spread over a field and rolled into soil. It is well known that the cutting height of plants during harvest shall not exceed 20 cm, the length of 75 % of crop residues shall not exceed 10 cm, and residues over 15 cm shall not exceed 5 %. Plant remains shall be spread evenly without rolls over a field. Immediately after harvesting, plant remains shall be rolled into soil with disc harrows to a depth of

12 cm, preventing it from drying out. Sufficient humidity ensures efficient activity of microorganisms and rapid decomposition of straw. Before turning the crop residues, it is desirable to apply nitrogen fertilizers, in particular ammonium nitrate at the rate of N_{10} per 1 ton of crop residues to compensate for the utilization of nitrogen by soil microorganisms, since crop residues rolling without nitrogen fertilizers leads to a dramatic decrease in the content of mineral nitrogen in the soil and reduces the yield of subsequent crops in crop rotation. Application of crop residues in the amount of 3.5-4.0 t ha⁻¹ with nitrogen compensation (N_{10} per 1 ton of crop residues) is equivalent to the application of 18–20 t ha⁻¹ of manure in terms of its effect on increase of soil fertility and crop yield (Holypan et al., 2003; Andrienco, 2011; Crutchfield, 1986; Lebid et al. 2006; Pabat, 2003; Cerepanov, 1991; Troeh and Thompson, 1993).

Mulching also improves the temperature profile, agrophysical condition of the soil, agrochemical and biological indicators. In addition, mulching significantly increases the effectiveness of mineral fertilizers, especially in arid growth environment. Under such extreme conditions crop yields increase by 20-25 % only due to mulching. The correct utilization of post-harvest residues is closely related to mechanical tillage that regulates their distribution on the field surface, which in turn is associated with protection from deflation, with moisture accumulation and the nature of their mineralization, humification (Crutchfield, 1986; Lebid et al., 2006; Pabat, 2003; Cerepanov, 1991; Troeh and Thompson, 1993).

Mulching cultivation is carried out with subsurface cultivators, chisels or diskers. According to the data of different scientists (Pabat, 1992; Lebid et al., 2006; Troeh and Thompson, 1993), each nonmoldboard tool leaves after cultivation different amount of post-harvest residues of the predecessor on the soil surface:

disk tillers and harrows (LDG-15, BDT-7, Great Plains Turbo-Max 3000TM/3500TM/400TM) leave 40-60 % residues on the surface;

subsurface cultivators (KPSH-5, UNIA KOS PREMIUM) – 85-95 %;

subsurface plows (PG-3-5, STAVR, PG-5) – 80-90 %;

anti-erosion cultivators (KPE-3.8, KT-3.9G) – 60-75 %;

chisel plows (PCh-4.5, Chip, ПЧ-10.01, PCh-6) – 60-70 %;

chisel cultivators (KPCh-5.4, Duolent) – 35-65 %;

soil spikers (BIG-3A, Great Plains UT3030) – 80-85 %;

stubble seeders (SZS-2.1, STS-2, Great Plains NTA3010/ADC1150) – 65-70 %.

2 MATERIALS AND METHODS

Experimental studies were conducted during 2011-2015 in the stationary experiment of the Institute of Grain Crops at the National Academy of Sciences of Ukraine in a short crop rotation: bare fallow – winter wheat – sunflower – spring barley – corn. The effectiveness of the board, differentiated and mulch tillage systems was studied in the crop rotation. Cultivation was carried out with the following implements: 1. Board – with a PLN-4-35 plow to a depth of 20-22 cm for spring barley and sunflower, 23-25 cm for corn, 25-27 cm for black fallow (autumn) 2. Chisel – with a chisel plow to a depth of 14-16 cm for sunflower and spring barley (in autumn); 3. Disk – with a BDT-3 harrow to a depth of 10-12 cm for spring barley and clean fallow (in autumn); 4. Subsoil – with a combined KShN-5.6 or KR-4.5 implement to a depth of 14-16 cm for corn and 12-14 cm for sunflower (autumn) in early fallow (in spring). Black fallow maintenance was based on the principles of minimization and varying of depth of cultivation from 10-12 cm in spring to 6-8 cm before wheat sowing. Clean fallow maintenance after the main cultivation in spring was carried out similar to black fallow maintenance.

All the grinded frondiferous mass of the predecessors was left in the field without subtraction and it was rolled with the above-mentioned implements against the background without fertilizers and with the application of mineral fertilizers together with crop residues. The experimental design included 3 fertilizer backgrounds: 1) without fertilizers + post-harvest residues; 2) $N_{30}P_{30}K_{30}$ + post-harvest residues; 3) $N_{60}P_{30}K_{30}$ + post-harvest residues. Mineral fertilizers were applied in the spring by spreading for preplant cultivation.

Agricultural techniques for growing field crops (winter wheat – Lytanivka variety, corn for grain – 295 SV Belozirskiy hybrid, sunflower – Yason hybrid, spring barley – Ilot variety) are generally accepted for the Steppe zone. For winter wheat and spring barley in the tillering phase the Esteron herbicide 1.2 and 0.8 l ha⁻¹ was applied, respectively, for corn and sunflower – Harness soil herbicide at a dose of 2.5 l ha⁻¹. Mineral fertilizers ($N_{30}P_{30}K_{30}$) for winter wheat were applied in autumn before sowing and additionally for plants nutrition – N_{30} in spring at booting stage. In the cultivation of corn, sunflower and spring barley, mineral fertilizers ($N_{30}P_{30}K_{30}$, $N_{60}P_{30}K_{30}$) were applied for presowing cultivation.

To comprehensively study the impact of tillage technologies and fertilizers on agrochemical, water-physical properties, formation of crop productivity, commercial efficiency in a stationary experiment, modern field, measuring-weighing, analytical and mathematical-statistical

research methods were applied according to generally accepted methods:

- density of soil structure was studied by the method of “cutting ring” in layers 0-10, 10-20 and 20-30 cm in four repetitions before sowing field crops and at the end of the growing season, in fallow in spring and at the end of fallowing (Vadunina, 1986).

- soil hardness was measured with a Reviakin hardness tester to a depth of 0-30 cm in the spring before sowing and at the end of the growing season (Vadunina, 1986);

- structural and aggregate composition of the soil was determined by the method of “dry” sieving on a column of sieves according to N.I. Savinov. Soil was sampled in the spring from layers 0-10, 10-20, 20-30 cm in ten places before sowing field crops and at the end of the growing season, in fallow in the spring and at the end of fallowing (Revut, 1972);

- anti-deflation assessment of the field surface depending on the tillage technique was determined by the degree of preservation of crop residues on the field surface and lumpiness of the upper layer 0-5 cm in spring before moisture closure and sowing of spring crops (Shiyatuy, 1971);

- availability of a conditional stubble on the field surface (pcs. m⁻²) was determined with the help of a formula:

$$S = Q/p \cdot d$$

where S – conditional stubble on the field surface (pcs. m⁻²);

Q – mass of air-dried crop residues per 1 m², g;

p – mass of one wheat stubble with a straw length of 20 cm (p = 0.26 g);

d – mass equivalent of the conversion of crop residues of different field crops into wheat stubble.

- lumpiness of the upper layer of soil (fractions larger than 1 mm) was determined within the period of accounting for the preservation of crop residues. An average sample weighing 500 g was prepared from 10 individual samples, followed by sieving the soil into fractions through a sieve column (Shiyatuy, 1971);

- the coefficient of wind resistance of the soil surface was determined by the formula:

$$W = A/Q$$

where W – coefficient of wind resistance;

A – maximum allowable wind operations according to E.I. Shiyatuy equal to 120 g (Shiyatuy, 1971);

Q – estimated or actual soil erosion by wind, g/m² for 5 minutes.

- depth of tillage was determined using a furrow depth indicator, 50 measurements were performed at each site. After determining the average depth, the co-

efficient of uniformity of cultivation was calculated and evaluated according to a five-point scale (Stebut, 1871);

- soil moisture was determined in a one and a half meter layer of soil by thermostatic-weight method (Vadunina, 1986; Dolgov et al., 1966). Samples were taken every 10 cm in three places of the site and two adjacent repetitions in spring before sowing of spring crops in the phase of earing, flowering, shot and in autumn before sowing of winter wheat, as well as at the end of growing season;

- total crop water consumption was determined by the method of water balance (Vadunina, 1986);

- soil for agrochemical analysis was sampled in the spring to a depth of 0-10, 10-20 and 20-30 cm for all the options of the experiment at five points of the field diagonally in the first and third repetitions. Plants were sampled before harvesting field crops. Sampling and preparation of samples for analysis were performed according to the methodology developed by Yu. K. Kydzin (Kydzin, 1963).

- agrochemical analyzes of soil samples was performed both standard and some specific, namely: general humus according to I.V. Tiurin in the modification of Orlova and Hrindel with spectrophotometric ending; total (gross) nitrogen and phosphorus by the method of K.E. Ginzburg, GM Shchekhlova, E.A. Wolfius (Ginzburg, 1975); the content of N-NO₃ in the soil without composting and after 7 days of composting – spectrophotometrically (Kravkov's method) (Borisova, 1968);

- the content of active forms of P₂O₅ and K₂O – with a solution of 0.5 N acetic acid (Vagenin, 1975); the content of readily available forms of phosphorus extracted by solutions of weak hydrochloric acid (Franceson's method) and neutral solution of potassium sulfate (Karpinski Zamiatin method) (Ginzburg, 1975);

- Keldal nitrogen, phosphorus – on a photoelectric colorimeter, potassium – on a flame photometer were determined in plant samples;

- protein, fat, starch and fiber in grains and seeds – on Infrapid-61;

- accounting for above-ground weediness of crops was accounted by the method of sites (1.0 m²) in the earing phase of early cereals and before the first inter-row cultivation in row crops, as well as after each cultivation of fallow with simultaneous weeding to determine species and their mass in air dried state. The accounting frame was superimposed on the diagonal of the site in 10 places (Veselovskiy et al., 1998; Ivachenco, 2001);

- yield accounting was carried out separately by the method of direct threshing (winter wheat, barley, peas) with the Sampo-500 combine (sunflower – Niva-Effect combine), corn – manually taking into account the humidity and impurity of products (Bulugin et al., 1999)

within phase of full grain maturity. After determining the impurity and moisture content of the grain, yield was reduced to 100 % purity and 14 % moisture. Yield data for all the crops were processed by the method of analysis of variance according to B.A. Dospekhov using computer technology (Dospekhov, 1985);

- assessment of crop rotation productivity depending on tillage and fertilizer systems was given by grain yield, amount of feed, grain units and digestible protein per 1 ha of crop rotation area, as well as the average yield of field crops. The calculation of feed, grain units and digestible protein was determined by multiplying the yield of the product by the normative coefficients (Tome, 1964);

- calculations of the economic efficiency of the studied measures were carried out according to the recommendations of the Institute of Agrarian Economics National Scientific Center and the Institute of Steppe Agriculture (Rubka et al., 2012);

The two-factor stationary experiment is based on the method of splitting plots with their sequential placement in triplicate. The size of the plots of the first order – 1500, the second – 375, the accounting area – 30-100 m².

The soil of the experimental field is ordinary low humus medium loam chernozem. The thickness of the humus horizon is 38-43 cm. The humus content in one layer is 0-30 cm – 4.2 %. Absorbed bases are mainly calcium 20.4 and magnesium 7.8 mg/eq per 100 g of soil. The degree of soil saturation with bases is 94.18 %. Due to this fact, the reaction of the soil solution is close to neutral (pH 6.6-6.8). The gross content of nutrients in one layer of soil is in the range of: total nitrogen – 0.15-0.19, phosphorus – 0.11-0.14, potassium – 2.0-2.4 %, active forms of phosphorus (in acetic extract according to Chirikov) – 9-10, exchangeable potassium (according to Maslova) – 14-15 mg per 100 g of soil.

The climate of the study area is temperate-continental with significant fluctuations in weather conditions over the years. The average annual air temperature is +9.6 °C, with a deviation in some years from 8.4 to 10.8 °C. The average annual rainfall is 509 mm and varies from 420.7 to 832.7 mm. Most of them (68 % of the annual amount) fall during the warm period (April-October) and are largely spent on evaporation, as well as runoff due to the predominance of heavy rainfall in the undulating terrain.

In recent decades, the world, and in particular Ukraine, has undergone significant agrometeorological changes in the direction of global warming.

Adverse weather conditions for growing field crops were in 2012 and 2013. The hydrothermal coefficient in the period of the greatest water consumption of plants (May – July) was equal to: 2011 – 0.8, 2012 – 0.6, 2013

– 0.7, 2014 – 0.9, 2015 – 0.8. The SCC index of less than 0.7 indicates the presence of soil and air drought that adversely affects the grain formation and filling.

Mathematical processing of field research data to determine the validity of differences was carried out using computer software and in accordance with the methodology (Dospikhov et al., 1985; Styl et al., 1977).

3 RESULTS AND DISCUSSIONS

According to the research results, the agrophysical indicators of the soil, regardless of its processing, were within the optimal parameters. The density of the soil did not exceed the critical limit – 1.35 g cm^{-3} in the cultivated layer and was 1.18 for plowing, 1.25 for chiselling, 1.26 for subsurface knifing, and 1.26 g cm^{-3} for disk tillage. It should also be noted that in case of shallow disk processing, differentiation of the processed layer was observed in terms of density with its increase in a layer of 10–20 cm to 1.3 g cm^{-3} . This is due to the mechanism of action of a soil tillage implement, as a result of which the above-mentioned layer is compacted.

At the beginning of spring field operations, during the years of research, regardless of the tillage system, favorable density conditions were developed for all studied field crops that were within the range of $1.09\text{--}1.32 \text{ g cm}^{-3}$ in the arable layer (0–30 cm). With shallow mulching due

to the reduction of the depth of loosening to 12–14, 14–16 cm there was some compaction of the layer 0–30 cm by $0.02\text{--}0.14 \text{ g cm}^{-3}$ that does not exceed the optimal density for crops growing.

Soil hardness during plowing in a layer of 0–30 cm was minimal – $5.0\text{--}8.7 \text{ kg cm}^{-2}$, the use of chiselling, subsurface knifing and disking contributed to an increase in indicators up to 11.9, 12.1 and 13.3 kg cm^{-2} , respectively, without exceeding the optimal parameters up to 21 kg cm^{-2} for field crops (Table 1).

The system of differentiated tillage, where the same implements were used as in mulching, but after other crops, occupied an intermediate position in terms of hardness.

The 0–5 cm sowing layer of soil for all the tillage systems was within the range of optimal hardness ($3.4\text{--}16.2 \text{ kg cm}^{-2}$), and in the layer of 5–15 cm there was an increase in hardness to $12.2\text{--}17.1 \text{ kg cm}^{-2}$, as compared with the top one – 1.1–3.5 times.

The soil layer of 15–25 cm was the most compacted both in the board tillage system and at application of disk, subsurface and chisel implements in differentiated and mulching systems.

The change in the hardness of the arable layer of the soil depended not only on the method of tillage, but also on the influence of the root system of a particular crop grown in the field. Thus, against the background of non-

Table 1: Average change in soil hardness indicators depending on tillage systems for 2010–2015, kg/cm^2

Soil tillage system (A factor)	Soil layers, cm	In the spring, at the beginning of field operations (B factor)					At the end of fallowing and crop growing (B factor)				
		complete fallow	winter wheat	sun flower	spring barley	corn	complete fallow	winter wheat	spring sunflower	barley	corn
Board	5	4.2	15.2	4.4	8.1	3.4	15.8	20.5	16.6	21.0	17.0
	15	5.8	15.2	6.5	10.8	5.7	21.1	18.2	20.7	18.4	21.0
	25	14.9	19.8	12.7	19.6	13.5	21.9	17.3	32.5	17.5	31.1
	0–25	7.8	15.9	7.1	11.8	8.3	18.1	18.6	20.8	19.7	20.2
Differentiated	5	14.6	16.3	7.0	8.3	4.1	14.9	22.2	16.2	25.1	17.9
	15	17.1	20.2	11.8	15.7	12.2	24.6	23.0	33.2	20.7	33.3
	25	16.8	24.1	12.9	20.1	16.8	24.1	21.0	33.0	22.3	33.4
	0–25	15.4	18.8	9.8	13.5	11.8	19.7	20.0	24.8	23.2	25.1
Mulching	5	16.2	17.7	6.5	10.4	11.3	19.8	28.4	19.4	29.3	20.1
	15	17.3	17.5	13.6	16.9	13.8	26.5	23.1	33.8	24.4	33.7
	25	22.8	18.9	15.0	18.9	14.9	26.9	22.2	33.6	22.4	33.8
	0–25	17.6	16.8	10.8	14.2	15.6	22.4	25.2	25.8	25.7	26.0
HIP _{0.95} , kg cm^{-2} , (0–25 cm layer)											
for A factor		4.5					1.8				
for B factor		4.8					2.3				
for AB interaction		7.3					4.2				

board cultivation, the following year, in the spring the hardness indicators in the 0-25 cm soil layer were distributed in the following order: after winter wheat – 9.8 kg cm⁻², spring barley – 15.6, corn – 17.6 kg cm⁻²; chisel cultivation – after winter wheat – 10.8 kg cm⁻², spring barley – 11.8, sunflower – 13.5 kg cm⁻².

These data demonstrate that crops with different types of root system have different effects on soil hardness. For example, crops of winter wheat with a highly branched root system and optimal plant density in the area can significantly improve the hardness of the arable layer, while corn, sunflower that have stronger roots but are grown at lower standing densities, have less impact on it. The hardness of the soil in winter wheat crops at the time of resumption of spring vegetation exceeded the areas of fall plowing by 1.08-3.00 times. It was the highest in the field with shallow loosening by fallow disk cultivation – 18.8 kg cm⁻² and the lowest – by plowing – 15.9 kg cm⁻².

The hardness of the arable layer changed in dynamics under the influence of precipitation, air temperature and the development of the root system. From the beginning of spring operations until the harvesting, it increased in winter wheat crops from 15.9-18.8 to 18.6-25.2 kg cm⁻², or 1.2-1.3 times, sunflower – from 7.1-10.8 to 20.8-25.8 kg cm⁻², or in 2.4-2.9 times, corn – from 8.3-15.6 to 20.2-26.0, or in 1.6-2.4 times, in areas of spring barley – from 11.8-14.2 to 19.7-25.7 kg cm⁻², or 1.7-1.8 times. At the end of the growing season of winter wheat and sunflower, as in the spring period, there was a clear tendency to increase the hardness of the soil of the arable layer with depth.

Deterioration of the arable layer in spring barley crops was negatively affected by high temperatures and lack of precipitation for a long time, and as a result of drying of the soil at the end of the growing season that can be judged by hardness, in particular the 0-10 cm upper layer exceeding deeper layers in 1.1-1.3 times, going beyond the optimal values (21.0-29.3 kg cm⁻²).

The impact of tillage on its hardness, from the moment of autumn, preserved until the end of the growing season of the crops. Thus, in particular, at the end of the growing season the tendency to decrease the hardness of the soil against the background of plowing (18.1-20.8 kg cm⁻²) is observed for all the crops, compared with the options of differentiated (19.7-25.1 kg cm⁻²) and mulching (22.4-26.0 kg cm⁻²) tillage systems, which is primarily due to the reduction of tillage depth and the peculiarity of the action of non-board implements without turning the layer on the soil.

Based on the research, it can be concluded that the use of all the methods of tillage, especially deep board tillage, helps to reduce hardness due to mechanical loosening.

Reducing the depth of soil loosening to 12-14, 14-16 cm, when using non-board implements, increases the hardness to 18.8 kg cm⁻² in the spring before crops sowing (0-30 cm layer) that does not exceed the maximum allowable parameters (21 kg cm⁻²) for growth and development of field crops. A significant increase in hardness at the end of the growing season to 18.1-26.0 % is primarily due to man-made burden, reduced density and porosity, deterioration of structural and moisture regime in the cultivated layer (0-30 cm) that further is restored to optimal parameters during the autumn-winter period due to increase of moisture and reverse freezing-thawing processes.

Structural analysis of the soil, carried out in the spring in a 0-30 cm layer before pre-sowing cultivation, demonstrated that, regardless of the methods of tillage, the amount of agronomically valuable structural aggregates with a size of 10-0.25 mm did not exceed 73.2-75.9 %. There was a tendency to increase the number of the most valuable structural aggregates with a size of 7-0.25 mm against the background of chisel and disk treatment in the presence of crop residues on the surface.

In general, if we characterize the structural state of the soil depending on the tillage systems, the number of valuable aggregates increases in ascending order: board – differentiated – mulching. The sum of agronomically valuable aggregates of 10-0.25 mm per fall plow in a layer of 0-30 cm after winter wheat before sowing sunflowers and after corn at the beginning of fallowing under the mulching system was 87.7-91.8 % and exceeded the board system option by 4.9-9.6 %.

Methods and systems of basic tillage had less overall impact on the structuring processes than the crops themselves and the plant remains left by them in the field. With shallow tillage, the number of the most valuable aggregates (10-0.25 mm) increased due to the reduction of man-made burden on the soil compared to the board. The mulching system of tillage had a significant advantage in soil structuring with the use of annual shallow tillage, leaving the post-harvest residues of the predecessor on the surface of the field.

The agrophysical properties of the soil, together with the presence of crop residues on its surface, are closely related to soil deflation (wind erosion). As it is known, soil resistance to deflation is determined by soil deflation. Deflation (the amount of soil particles transported by wind) is the most objective indicator of the degree of soil wind resistance. It mainly depends on the properties of the upper soil layer (granulometric composition, cloddiness and cohesion of soil aggregates, amount of stubble, etc.) (Barwicki et al., 2012; Bakker et al., 2008; John, 2013; Novakovsky, 2017; Tarariko, 2017; Baliuk et al., 2016; Rasmussen, 1999; Javůrek et al., 2008). For most soils with the content of clods larger than 1 mm in the

upper layer of 0-5 cm and in an amount above 60 % of the dry mass favorable conditions are created for resistance to wind blowing, and when the amount is less than 50 %, the blowing of soil particles increases (Zayceva, 1970). In our studies, immediately after tillage in autumn, the cloddiness (aggregates > 1 mm) of the upper layer (0-5 cm) of the soil, regardless of fallow treatment, was 61.0-62.9 %, and did not decrease below 60 %, that is, it was wind resistant. During the winter period, as a result of the influence of oppositely directed processes of freezing – thawing, moistening – drying out, soil aggregates were destroyed to erosion-hazardous sizes, the cloddiness of chernozem decreased by 1.3-1.4 times and amounted to only 43-46 %, as a result of which they can deflate on open plains and wind-swept slopes (Table 2).

According to theoretical calculations, according to the method of E.I. Shiyatuy, soil deflation by wind is allowed to the extreme limit 120 g per 5 minutes of exposure. When the erosion is less than or equal to 50 g, the soil surface is considered to be highly wind-resistant, and at values of 50-120 g it is considered to be moderately wind-resistant. In spring conditions (the period of manifestation of maximum deflation), in order to prevent soil blowing out, it is required to have 8-10 pieces/m² of conditional stubble 20 cm long in terms of winter wheat for each percent reduction in the top layer cloddiness (Shiyatuy, 1971).

Therefore, during the destruction of erosion-resistant particles (aggregates > 1 mm), plant crop residues

of the predecessor left on the soil surface that protect its surface from blowing silt fractions in spring, are of great importance. The most of conditional stubble on the surface remains, of course, in the early fallow (without tillage in autumn) 630 pcs m⁻². A significant amount of it was also after disk processing – 333 pcs m⁻². Early fallow is a reliable method for wind erosion (deflation) combat in the spring. Even strong winds with a speed of more than 15 m s⁻¹ in early fallow are not able to blow out more than 5-12 g m⁻² of soil in 5 minutes of exposure, while in case of board tillage these figures increase by 11-26 times and amount to 134 g m⁻² (Figure 1).

The coefficient of wind resistance of the surface (the ratio of the allowable level of deflation of 120 g m⁻² to its actual value) was the highest in the early fallow – 24, due to the protection of the surface by crop residues. In summer, during fallow care, during cultivation, the risks of soil deflation increase significantly, even for early fallow. But still, the soil is more resistant to blowing out in case of options of non-board tillage compared to the board. The use of board tillage in fallow, as well as for all the crops in the crop rotation, contributed to the emergence of maximum wind erosion (deflation).

Early fallow is not only a radical method of combating wind erosion, but also water erosion. The runoff of melt water in spring does not create significant soil erosion in such a case. This is facilitated by an increase in its density, protection by snow and crop residues. In such a case the water flow breaks up into small streams and

Table 2: Indicators of anti-deflation resistance of soil in spring in a field of complete fallow, depending on the methods of cultivation

Soil anti-deflation resistance indicators	Soil cultivation	Soil anti-deflation resistance value
Quantity of conditional stubble on the soil surface, pieces m ⁻²	board (plowing)	20
	non-board (disk)	333
	non-board (subsurface, early fallow)	630
Cloddiness (aggregates > 1 mm) in 0-5 cm soil layer	board (plowing)	46
	non-board (disk)	43
	non-board (subsurface, early fallow)	45
Clog mechanical resistance, %	board (plowing)	82
	non-board (disk)	67
	non-board (subsurface, early fallow)	75
Soil deflation by wind, g m ⁻² ·5 min.	board (plowing)	134
	non-board (disk)	113
	non-board (subsurface, early fallow)	5
Surface wind resistance coefficient	board (plowing)	0.89
	non-board (disk)	1.06
	non-board (subsurface, early fallow)	24.0

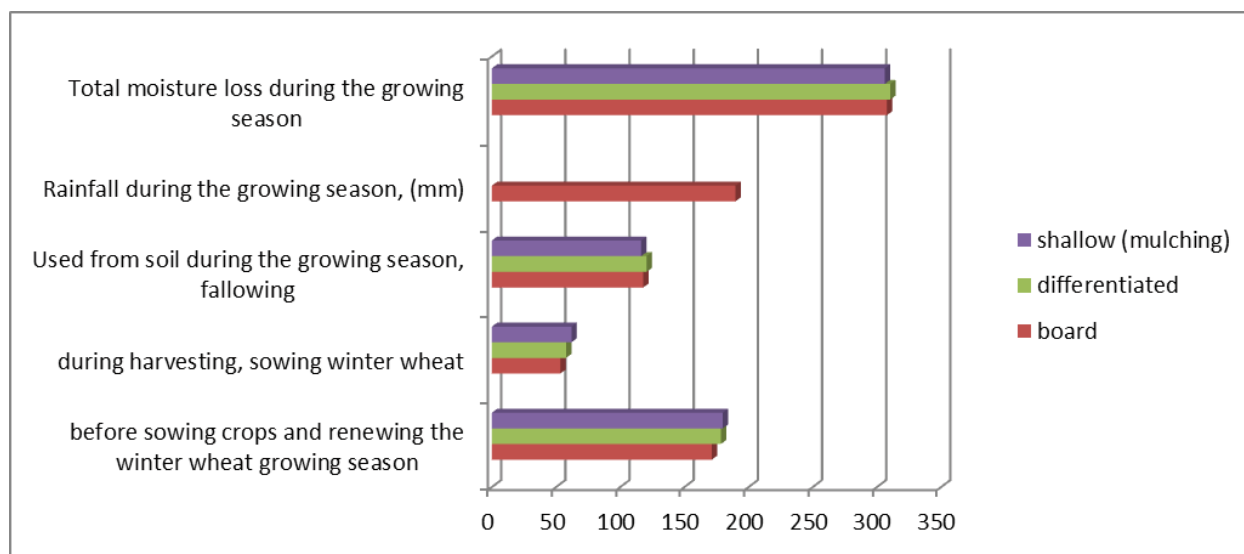


Figure 1: Average moisture balance in short crop rotation against the background of different tillage systems for 2011-2015, mm

loses speed mainly due to mechanical braking. With a high clogging ability of the soil preparation, soil washout outside the field was 1.5-4.3 t ha⁻¹, which is 4-12 times less than in case of plowing (18.6 t ha⁻¹).

The resistance of early fallow to erosion of heavy summer precipitation increases if there is more than 2.5 t ha⁻¹ of plant substrate on the surface, postponement of the main cultivation to the period of mass growth of weeds (May), its carrying out with non-board implements to a loosening depth of 12-14 cm in order to preserve the mulching screen and to create a cloddy structure of the topsoil. Under the conditions of artificial sprinkling with an intensity of 3.5 mm min⁻¹. (end of June, slope of 2.5°) in areas of board tillage with the fallow maintenance technology recommended for the zone, the runoff began in 3.2 minutes when supplying 11.2 mm of water, while in the early fallow with spring processing – after 7.6 minutes and supply of 26.6 mm of precipitation. Soil permeability and runoff turbidity in this case were 1.08 mm min⁻¹ and 25 g l⁻¹, against 0.65 mm min⁻¹ and 39 g l⁻¹, respectively, under control conditions.

The transition from black fallow to early fallow, against the background of mulching the soil surface with crop residues of the predecessor, improves the structure of ordinary chernozem, while reducing the amount of silty fractions (< 0.25 mm) that are most amenable to anthropogenic pressure to a safe indicator of 5.4-5.6 %. The content of agronomically valuable aggregates, 10-0.25 mm in size, at the end of fallow in the arable layer, on the contrary, increases in relation to autumn plowing to 89-90 %. The level of these indicators makes it possible to state that with a positive balance of biogenic compounds, the presence of a sufficient amount of energy material

and the absence of erosion, the renewal of the structure in early fallows occurs in a self-regulation mode inherent in natural analogs of fallow or virgin lands (Medvedev, 2007).

According to the level of accumulation of winter precipitation, early fallow had an annual advantage over autumn plowing. This can be explained by the formation of a very dense protective screen, created by standing stubble and grinded crop residues. In the area that has not been cultivated since autumn, there is a significant decrease in wind speed in the aboveground airspace, as well as earlier and more uniform snow deposition, an increase in its viscosity and density. In combination with high buffering and retaining properties of early fallow, this causes less water loss to runoff, evaporation, freezing and blowing, and as a result, it contributes to an increase in the coefficient of precipitation absorption and additional accumulation of moisture in the root-active soil layer (0-150 cm) compared to the board tillage by an average of 130 m³/ha.

As for the reserves of efficient moisture in the spring in a one and a half meter soil layer, on average over five years of research, they amounted to 171.4 mm for the board tillage system, 178.5 – differentiated, and 179.9 mm -mulching. The advantage in the accumulation of moisture in the autumn-winter period by 7.1-8.5 mm (71-85 t ha⁻¹) was observed against the background of differentiated and mulch tillage systems in comparison with board tillage. This is due to the presence of post-harvest residues on the soil surface, wavy microrelief during chiselling. Ultimately, this contributed to a greater accumulation of snow during December-January with a general shortfall in the standard amount of precipitation

and the virtual absence of significant snow cover during the years of the study (Table 4).

The total consumption of moisture from the soil varied in a narrow range of 306.2-310.4 mm and almost did not change depending on the tillage system. It should be noted more economical moisture consumption by field crops against the background of a shallow mulch tillage system, as evidenced by a decrease in the moisture consumption coefficient by 13.4 mm t⁻¹ compared to board tillage.

According to the results of agrochemical analysis, in the mulch tillage system in crops of corn, spring barley, sunflower, with an average and increased supply of N-NO₃, there was a tendency to reduce the amount of nitrates by 1.4-3.0 mg kg⁻¹ compared to the board system. With an increased and high level of phosphorus and potassium supply, the difference in the range of 11-29 mg kg⁻¹ in the content of these elements in the cultivated layer between the options of mulching and board tillage is considered insignificant. The existing reserves of P₂O₅ and K₂O in the 0-30 cm layer before sowing field crops were sufficient to form a high grain yield, regardless of the studied tillage and fertilizer systems.

The use of shallow mulch tillage with crop residues left in crop rotation fields is of great importance for the renewal of soil fertility, especially in the context of a reduction in the use of organic and mineral fertilizers in recent decades. The stubble crop residues of field crops left on the field return a significant amount of previously alienated nutrients, their amount depends mainly on the yield of by-products and the biological characteristics of the crops. The largest number of nutrients is returned with crop residues of winter wheat (N – 57.4-79; P₂O₅ – 13.1-17.3; K₂O – 94.0-140.6 kg ha⁻¹), sunflower stalks (N – 50, 1-70.5; P₂O₅ – 13.2-16.4; K₂O – 148.5-186.5 kg ha⁻¹) and corn (N – 53.3-65.1; P₂O₅ – 29.9-33, 3; K₂O – 90.4-103.6 kg ha⁻¹) that is explained by the high yield of by-products and the significant content of nutrients in them. A significantly smaller amount (by 1.5-2.0 times) of nutrients is returned with by-products of spring barley (N – 32.9-43.2; P₂O₅ – 7.8-10.4; K₂O – 43.5-63.7 kg ha⁻¹) due to the low yield of straw compared to winter wheat straw, corn and sunflower stalks (Table 3).

A significant amount of nutrients returns to the soil and the root system of field crops. For example, the roots of winter wheat after their mineralization leave in soil: N – 40.2-63.8; P₂O₅ – 6.2-8.9; K₂O – 13.9-19.2 kg ha⁻¹ that is somewhat less compared to crop residues, especially in potassium (6-8.5 times), but making up a significant amount in the total amount. The same patterns are inherent in the content of nutrients in the root residues of sunflower, corn and spring barley, the decrease in their number in comparison with the nutrients of above-

ground residues in nitrogen was 1.4-3.1; phosphorus 2.4-4.2; potassium 6.2-6.8 times.

In its total mass, crop residues (root + stubble) leave a significant amount of organic matter, which, during humification and mineralization, is partially converted into humus and active nutrients (N-NO₃, P₂O₅, K₂O). The total amount of stubble substances involved in the biological cycle was distributed in cereal crops by individual plant organs in the following ratio: main product – 44 %, by-product – 39-40 %, root system – 16-17 %, in sunflower – 32, 52 and 16 % respectively.

Relative indicators of the possible reuse of macronutrients after the mineralization of the mass of roots and by-products of cultivated crops are 48-53 % for N, P₂O₅ – 30-34 %, K₂O – 72-90 % of the volume of their biological circulation for crop formation, that is, when planning fertilizer systems in the crop rotation there should be taken into account, first of all, the compensation of the used nitrogen and phosphorus.

The use of crop residues as an organic fertilizer provides energy for the culture soil-forming process in agroecosystems, subject to the application of nitrogen fertilizers (nitrogen compensation) of 8-10 kg of active ingredient per ton of crop residues to ensure the vital ac-

Table 3: The content of humus, gross nitrogen and phosphorus under the influence of various tillage systems in 2015, %

Tillage system	Soil layer	Grain-fallow-row crop rotation		
		humus	nitrogen	phosphorus
Without fertilizers + post-harvest residues				
Board	0-10	4.46	0.22	0.17
	10-20	4.29	0.21	0.15
	20-30	3.90	0.20	0.14
	0-30	4.22	0.21	0.15
Shallow (mulching)	0-10	4.64	0.23	0.15
	10-20	4.25	0.21	0.15
	20-30	3.96	0.19	0.14
	0-30	4.28	0.21	0.15
Post-harvest residues + N ₃₀₋₆₀ P ₃₀ K ₃₀				
Board	0-10	4.35	0.22	0.16
	10-20	4.29	0.21	0.14
	20-30	4.05	0.20	0.14
	0-30	4.23	0.21	0.15
Shallow (mulching)	0-10	4.66	0.23	0.16
	10-20	4.24	0.21	0.16
	20-30	4.06	0.20	0.15
	0-30	4.32	0.21	0.16
HIP _{0.95} , % (0-30 cm layer)		0.05	-	-

tivity of microorganisms. It is best to use nitrogen in the ammoniac or amide form, i.e. ammonium sulfate, ammonium chloride or urea. At the same time, the use of mineral soil nitrogen is leveled and the process of mineralization of organic substances is inhibited due to the high biogenicity of the soil. During the decomposition of root and stubble residues of crops with a relatively low nitrogen content, mineralization processes prevail over humification processes, since nitrogen-free humus compounds are unstable and quickly mineralize. It has been established that for the root residues of winter wheat, the humification coefficient is 0.15-0.18 (C : N – 35-40 : 1), for straw – approximately 0.10 (C : N – 80 : 1). The coefficient of humification of organic fertilizers (manure) is 0.2-0.3 (C : N – 25-35 : 1). The joint use of crop residues and mineral fertilizers in the recommended doses increases the humification coefficient by 23-25 %.

The use of crop residues (straw of early cereals, sunflower and corn stalks) as an organic fertilizer is also of great environmental importance:

- crop residues evenly spread over the field protect the soil from erosion, drying out and compaction processes;

- large amount of organic matter is utilized, and the half-life elements are completely absorbed by the soil complex;

- organic mass is re-introduced in the circulation of mineral and organic plant nutrition to form a new crop;

- organic matter decomposes in the soil for a long time, does not pollute it with high concentrations of nitrate nitrogen, organic phosphorus and potassium;

- stable balance of input into the soil and losses of plant nutrients from crop residues eliminates the washing out of active elements and their removal with surface runoff to water bodies;

- leaving crop residues on the field contributes to the development of soil fauna that increases the activity of bacteria, worms and other organisms, improves the agrochemical and physical properties of the soil.

The use of post-harvest crop residues in our experiments in combination with mineral fertilizers in moderate doses of $N_{30-60}P_{30}K_{30}$ caused some changes in the potential and effective soil fertility. Systematic – within 6 years – rolling in the soil (50 % with shallow mulching and almost complete with plowing) of biomass by-products of crop rotation, even without nitrogen to compensate, provided a deficit-free balance of humus. With the initial humus content of the arable layer of 4.2 %, after 6 years, in case of options without mineral fertilizers, but with leaving of crop residues, the content of total humus in the layer of 0-30 cm in the grain-fallow-row crop rotation was 4.22-4.28 % (higher by 0.02-0.08 percentage points (p.p.)), and in combination with the application of mineral fertilizers it increased by 4.23-4.32 %, or 0.03-0.13 p.p. (Table 3). The application of mineral fertilizers in combination with crop residues contributed to the

Table 4: Average influence of basic tillage systems and fertilizers on crop rotation productivity for 2011-2015, t ha⁻¹

Sequence of crops in a crop rotation	Soil tillage system and fertilizers in crop rotation					
	board		differentiated		mulching	
	post-harvest residues	post-harvest residues + $N_{48}P_{18}K_{18}$	post-harvest residues	post-harvest residues + $N_{48}P_{18}K_{18}$	post-harvest residues	post-harvest residues + $N_{48}P_{18}K_{18}$
Complete fallow	-	-	-	-	-	-
Winter wheat	4.51	4.74	4.45	4.88	4.30	4.82
Sunflower	2.38	2.66	2.24	2.68	2.31	2.71
Spring barley	2.51	2.90	2.36	2.88	2.05	2.68
Corn	5.01	5.73	4.94	5.64	4.83	5.59
	Obtained per hectare of crop rotation area, t					
Total grain	2.41	2.67	2.35	2.68	2.23	2.62
Including winter wheat	0.90	0.95	0.89	0.98	0.86	0.96
Feeder grain	1.50	1.73	1.46	1.70	1.38	1.65
Grain yield	4.01	4.46	3.92	4.47	3.73	4.36
Output of feed units	3.57	3.98	2.87	3.99	3.35	3.92
Output of digestible protein	0.40	0.44	0.38	0.44	0.37	0.44
Output of grain units	3.26	3.62	3.15	3.64	3.08	3.59

increase of the humus coefficient and, accordingly, to the greater accumulation of humus not only by shallow mulching, but also by the use of board tillage.

In general, there was a tendency to improve the humus condition of the soil with systematic shallow (mulching) tillage in short crop rotations by reducing mineralization processes and increasing humification processes compared to plowing. The content of gross nitrogen and phosphorus in the soil changed little under the influence of the studied agricultural practices.

In addition to the positive aspects, mulch tillage has a significant drawback that consists in an increase in weed infestation of early grain crops and fallow crops by 1.4-1.6 times, row crops by 1.4-1.8 times, which in some years necessitates the use of soil and postemergent herbicides for reliable control of weed infestation of crop rotation fields, preventing a decrease in their productivity. The application of mineral fertilizers at a dose of N_{30-60} in combination with crop residues of the predecessor increases the competitiveness of cereals to weeds by increasing the optical density of crops. In general, according to the scale of I.V. Veselovskiy, weeds increased in crop rotation in ascending order: board tillage system – weed level is low, differentiated – medium, shallow (mulching) – high (Veselovskiy et al., 1998; Ivachenco, 2001).

The productivity of field crops in a 5-field grain-fallow-row crop rotation was determined mainly by the application of mineral fertilizers, rather than tillage. The main tillage systems on the plots fertilized with mineral fertilizers, together with crop residues, turned out to be equivalent in all productivity indicators: grain yield (2.42-2.68 t ha⁻¹), grain units (3.37-3.64 t ha⁻¹), fodder units (3.65-3.99 t ha⁻¹) and digestible protein (0.41-0.44 t ha⁻¹) per hectare of crop rotation area with a slight downward trend in shallow mulch tillage. In case of option with crop residues without mineral fertilizers, the system of board and differentiated tillage had an advantage in all productivity indicators, due to a slightly better nutritional schedule (Table 4). Grain yield with board tillage system was higher by 0.18 t ha⁻¹ (7.5 %), grain units – 0.18 (5.5 %), fodder units – 0.22 (6.2 %), digestible protein – 0.03 t/ha of crop rotation area (7.5 %) compared to shallow mulching.

Mineral fertilizers applied in moderate doses ($N_{48}P_{18}K_{18}$ per 1 ha of crop rotation area), together with crop residues, significantly increased the productivity of the crop rotation as a whole. The maximum increase in grain yield from the use of $N_{48}P_{18}K_{18}$ with the board tillage system was 0.26 (9.7 %), grain units – 0.36 (9.9 %), fodder units – 0.41 (10.3%), digestible protein – 0.02 (5.0%) t ha⁻¹ of crop rotation area. The introduction of $N_{48}P_{18}K_{18}$ with a differentiated processing system increased the yield of grain by 0.33 (12.3 %), grain units – 0.49

(13.5 %), fodder units – 1.12 (28.0 %), digestible protein – 0.06 (13.6 %) t ha⁻¹ of crop rotation area. The use of $N_{48}P_{18}K_{18}$ in crop rotation with a shallow (mulching) tillage system gave an increase in grain yield by 0.39 (14.9 %), grain units – 0.51 (14.2 %), fodder units – 0.57 (14.5 %), digestible protein – 0.07 (15.9 %) t ha⁻¹ of crop rotation area. According to the research results, the highest gains from mineral fertilizers in terms of productivity were inherent in a shallow (mulching) background with characteristic more stringent conditions of the phytosanitary state and nutritional schedule. The introduced mineral fertilizers in moderate doses increase the productivity of the crop rotation by more than 14 % compared with the board tillage system and somewhat better initial conditions of mineral nutrition.

The use of alternative mulching methods for the basic tillage (disking, chiselling, subsurface knifing) for field crops makes it possible to optimize the operating costs of tillage, in particular, to save fuel and energy resources when introducing disking 15.7-17.6 l ha⁻¹, chiselling 7.0-8.3, subsurface knifing 17.4-22.1 l ha⁻¹, which ultimately has a positive effect on conditionally net income and an increase in the level of profitability of agricultural products by 5-14%.

4 CONCLUSIONS

1. Agrophysical indicators of the soil, regardless of its processing, were within the optimal parameters. The density of the soil did not exceed the critical limit – 1.35 g cm⁻³ in the cultivated layer and was 1.18 for plowing, 1.25 for chiselling, 1.26 for subsurface knifing, and 1.26 g cm⁻³ for disk tillage. Soil hardness during plowing in a layer of 0-30 cm was minimal – 5.0-8.7 kg cm⁻², the use of chiselling, subsurface knifing and disking contributed to an increase in indicators up to 11.9, 12.1 and 13.3 kg cm⁻², respectively, without exceeding the optimal parameters up to 21 kg cm⁻² for field crops. Structural analysis of the soil, carried out in the spring in a layer of 0-30 cm before pre-sowing cultivation, showed that, regardless of the methods of tillage, the amount of agronomically valuable structural aggregates with a size of 10-0.25 mm did not exceed 73.2-75.9 %. There was a tendency to increase the number of the most valuable structural aggregates with a size of 7-0.25 mm against the background of chisel and disc treatment in the presence of crop residues on the surface. There was a tendency to increase the number of the most valuable structural aggregates with a size of 7-0.25 mm against the background of chisel and disk treatment in the presence of crop residues on the surface.

2. To protect the soil from wind erosion (deflation), the most of conditional stubble on the surface remains, of course, in the early fallow (without tillage in autumn) – 630 pcs m⁻². A significant amount of it was also after disk

processing – 333 pcs m⁻². Early fallow is a reliable method to wind erosion (deflation) combat in the spring. Even strong winds with a speed of more than 15 m s⁻¹ in early fallow are not able to blow out more than 5-12 g m⁻² of soil in 5 minutes of exposure, while in case of board tillage these figures increase by 11-26 times and amount to 134 g m⁻².

3. Application of shallow (mulching) tillage provides additional accumulation of efficient moisture in the autumn-winter period by an average of 71-85 t ha⁻¹ compared to board tillage due to the presence of post-harvest residues on the soil surface.

4. Systematic rolling in the soil (50 % with shallow mulching and almost complete with plowing) of biomass by-products of crop rotation, even without nitrogen to compensate, provided a deficit-free balance of humus. With the initial humus content of the arable layer of 4.2 %, after 6 years, in case of options without mineral fertilizers, but with leaving of crop residues, the content of total humus in the layer of 0-30 cm in the grain-fallow crop rotation was 4.22-4.28 % (higher by 0.02-0.08 percentage points (p.p.)), and in combination with the application of mineral fertilizers it increased by 4.23-4.32 %, or 0.03-0.13 p.p.

5. In terms of productivity, different tillage systems (board, differentiated, shallow (mulching)) in the 5-field crop rotation were found to be equivalent, except for the options without the application of mineral fertilizers, where the shallow (mulching) system was inferior to the differentiated and board by 5.5- 7.5 %.

The obtained results are of great importance for farms of various forms of land ownership in the steppe zone, as they help to preserve the fertility of chernozem and to protect it from moisture erosion, deflation, etc. The conducted research will be continued in a long-term stationary experiment to identify the dynamics of the balance of humus, erosion processes under climate change.

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The authors declare that they have no competing interests.

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